National Aeronautics and Space Administration

The Operational Land Imager: Spectral Uniformity

Julia A. Barsi
Science Systems and Applications, Inc.

Brian L. Markham, Jeffrey A. Pedelty
NASA/Goddard Space Flight Center

August 23, 2011

SPIE
Earth Observing
Systems XVI

data continuity mission

LDCM
LANDSAT

NASA GSFC / USGS EROS

www.nasa.gov **www.usgs.gov**

Outline

- Spectral requirements
- Focal plane
- Component-level testing
- Out-of-band testing
- Instrument-level testing
- Spectral Uniformity

OLI

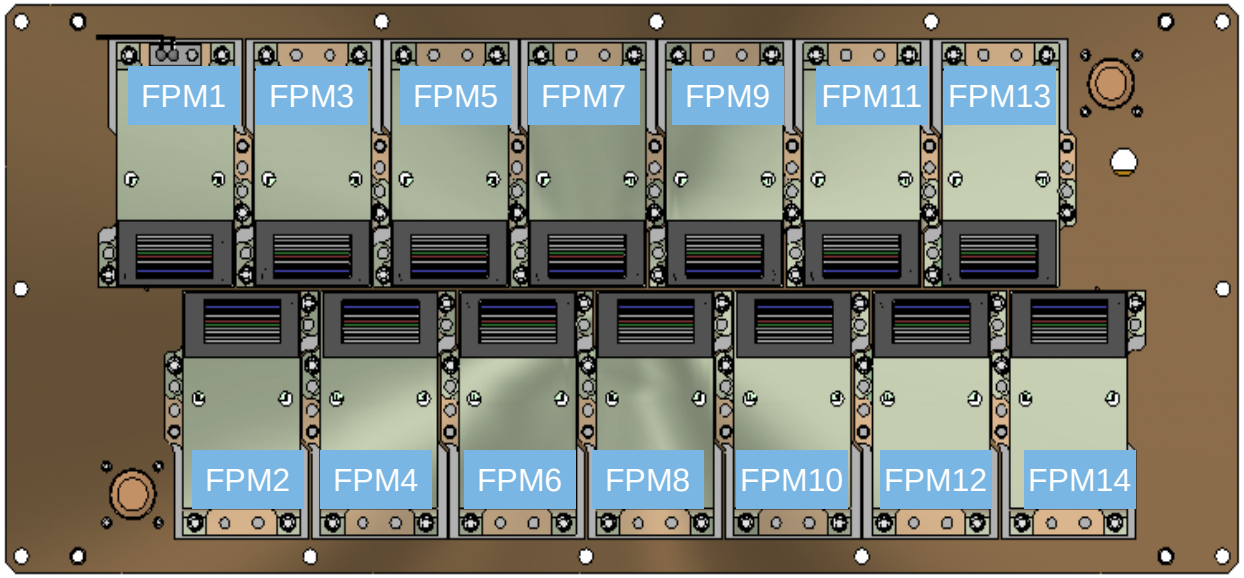
Operational Land Imager Spectral Requirements

- Spectral band edges
- Center wavelength tolerance
- Minimum bandwidth (bands 7, 8)
- Average in-band response
- Minimum in-band response
- Flatness between 0.8 response points
- Slopes of band edges (two cases)
- Non-integrated out-of-band response
- Integrated out-of-band response
- Spectral bandpass uniformity
- Radiometric uniformity

Band Number	Band Name	Center wavelength (nm)	Bandwidth (nm)
1	Coastal/ Aerosol	443	20
2	Blue	482	65
3	Green	562	75
4	Red	655	50
5	NIR	865	40
6	SWIR 1	1610	100
7	SWIR 2	2200	200
8	PAN	590	180
9	Cirrus	1375	30

OLI Focal Plane

- Pushbroom design
- Focal Plane Array
  - Consists of 14 modules to cover the 15-degree field of view
  - 6919 detectors per multi-spectral band (~13000 for Pan band)
- Focal Plane Module (FPM)
  - 494-detector array for each multi-spectral band (988 for Pan band)
  - Silicon PIN detectors for VNIR bands, HgCdTe detectors for SWIR bands
  - Butcher-block filter assemblies cover the detector arrays



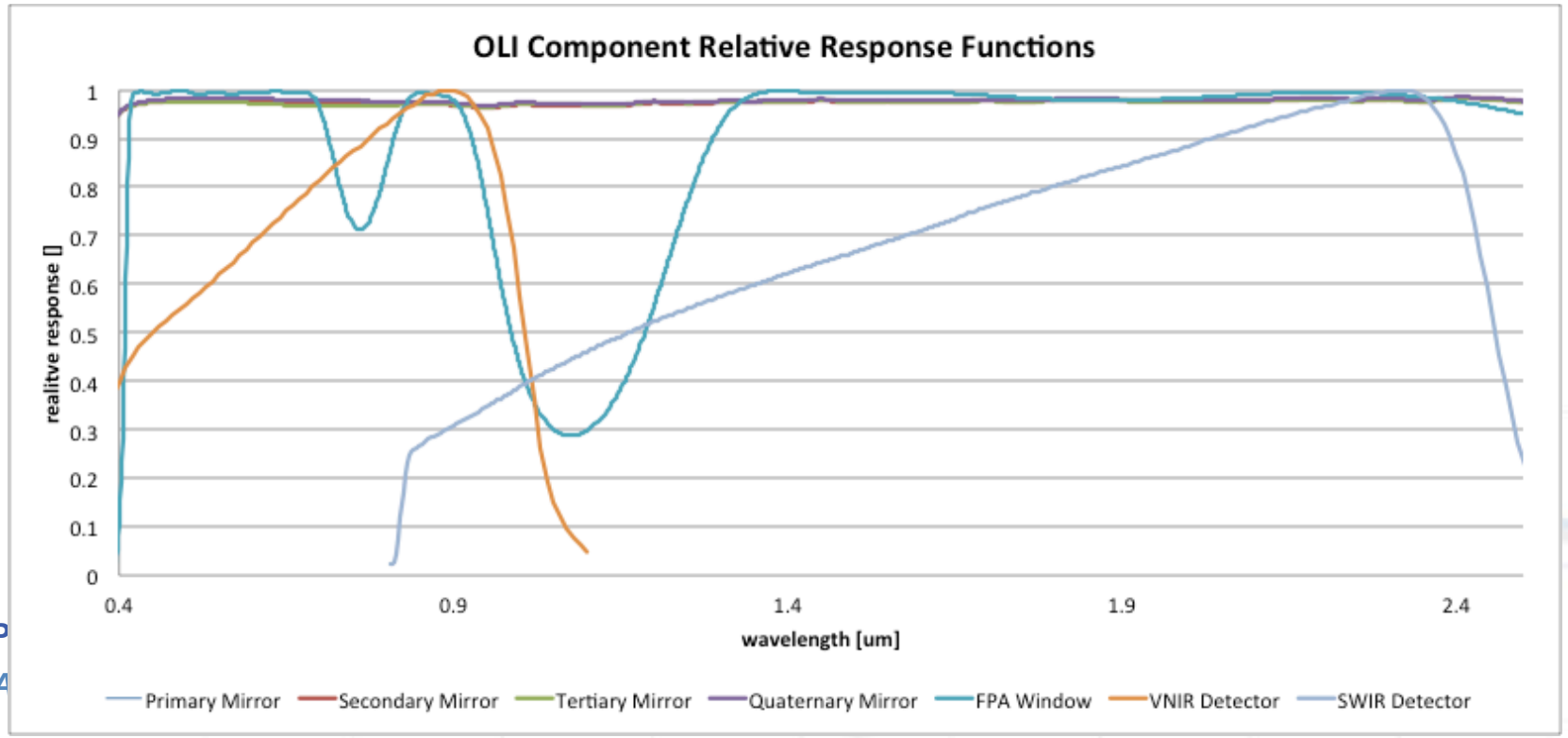
Filter Assemblies

- Spectral filter wafers manufactured in large sheets
  - Cut into sticks for incorporation onto the OLI focal plane
- Due to yield, most bands include filter sticks from more than one wafer
- Spectral differences between wafers will lead to spectral differences between modules
- Table indicates the source wafer for the filter stick for each module.

OLI FPM number	CA	Blue	Green	Red	NIR	Cirrus	SWIR1	SWIR2	Pan
1	2	3	1	1	2	3	2	1	2
2	1	1	1	1	1	2	1	1	1
3	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1
5	2	1	1	1	2	2	2	1	2
6	1	1	1	1	1	2	2	1	1
7	2	3	1	1	2	3	2	2	2
8	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1
10	1	1	1	1	2	2	2	1	2
11	1	1	1	1	1	2	1	1	1
12	1	1	1	1	1	2	1	1	1
13	2	3	1	1	2	3	2	2	2
14	1	1	1	1	1	1	1	1	1

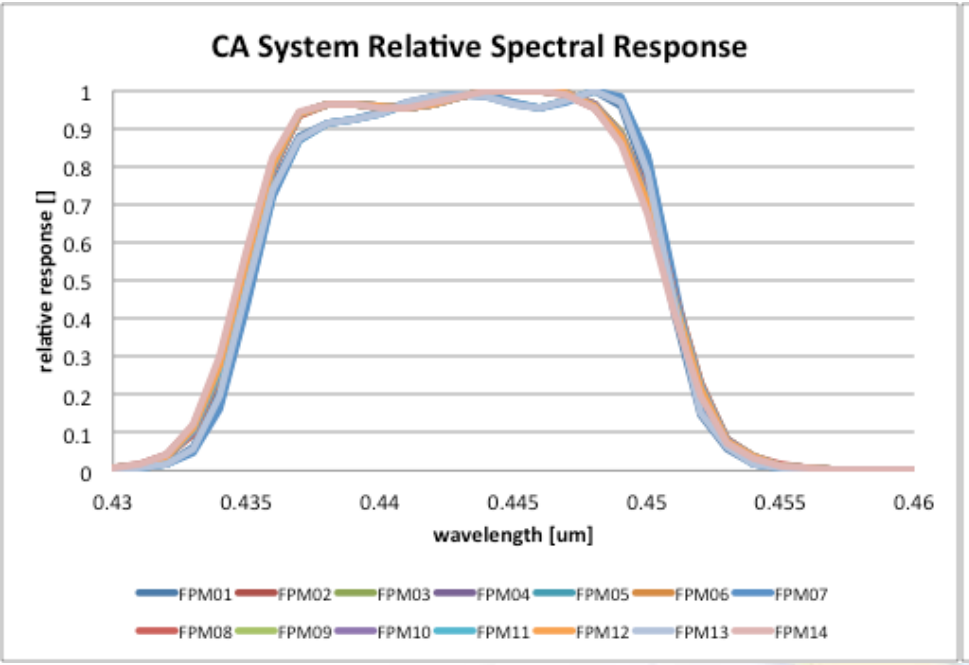
Component-level spectral measurements

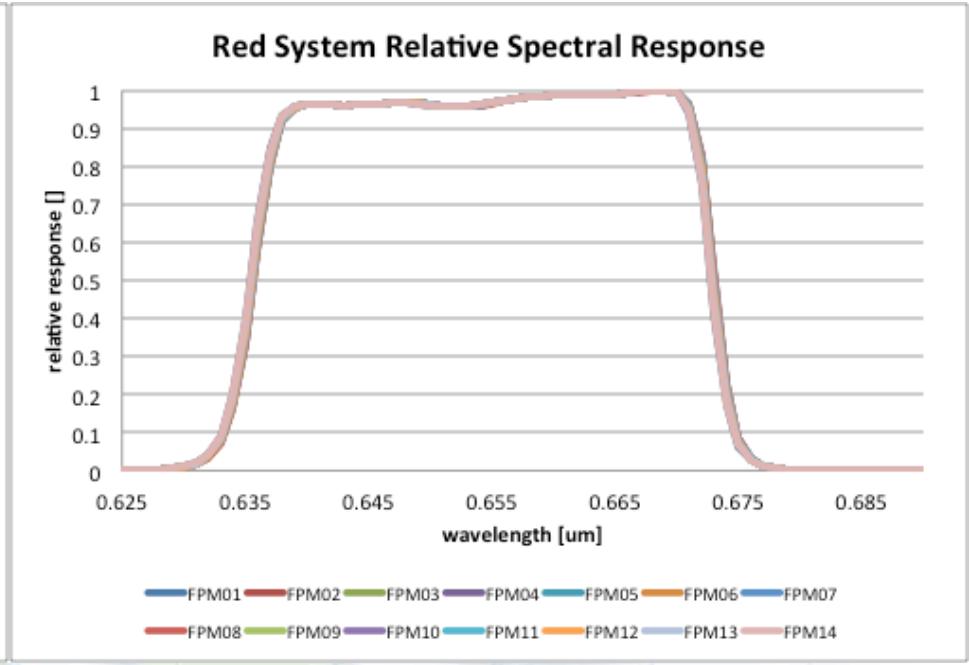
- Spectral measurements of each component of the optical path were taken before assembly
  - Witness samples of the four mirrors of the telescope
  - Witness sample of the Focal Plane Array window
  - Many samples of each detector type (VNIR and SWIR)



Component-level spectral measurements

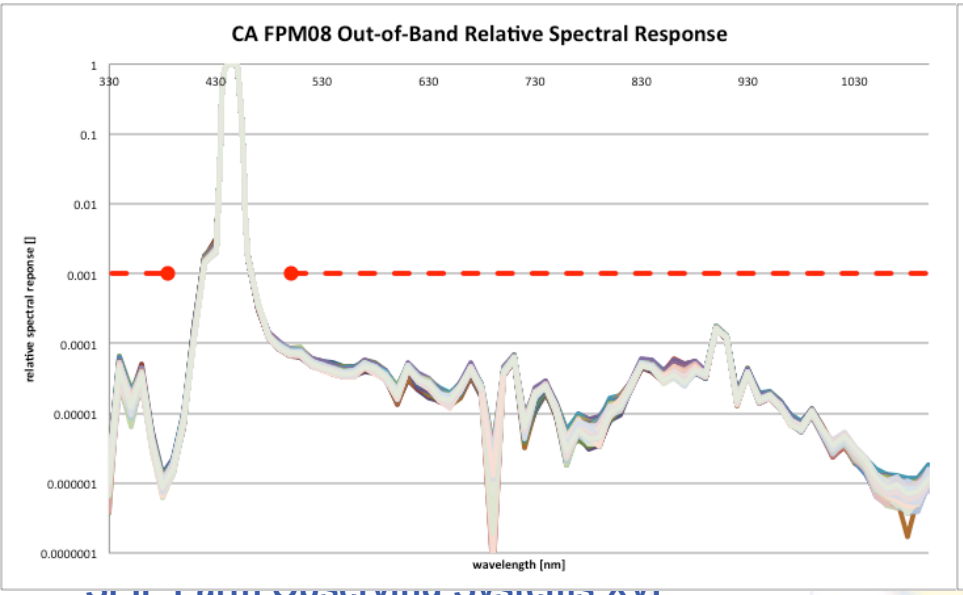
- Spectral measurements of each component of the optical path were taken before assembly
  - Nine measurements of each spectral filter wafer
- All component-level measurements were convolved together to produce an estimated system-level response

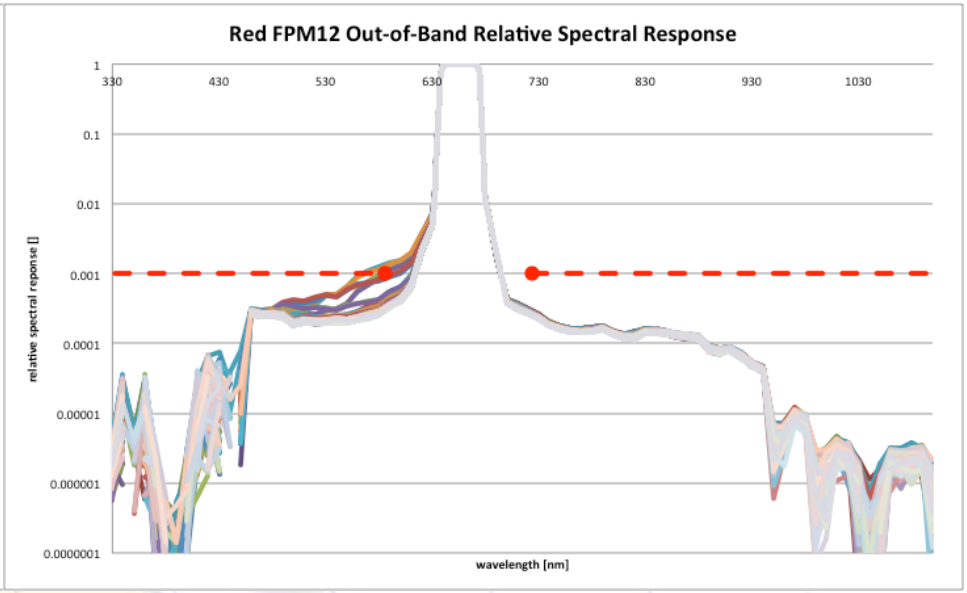




Module-level Out-of-Band measurements

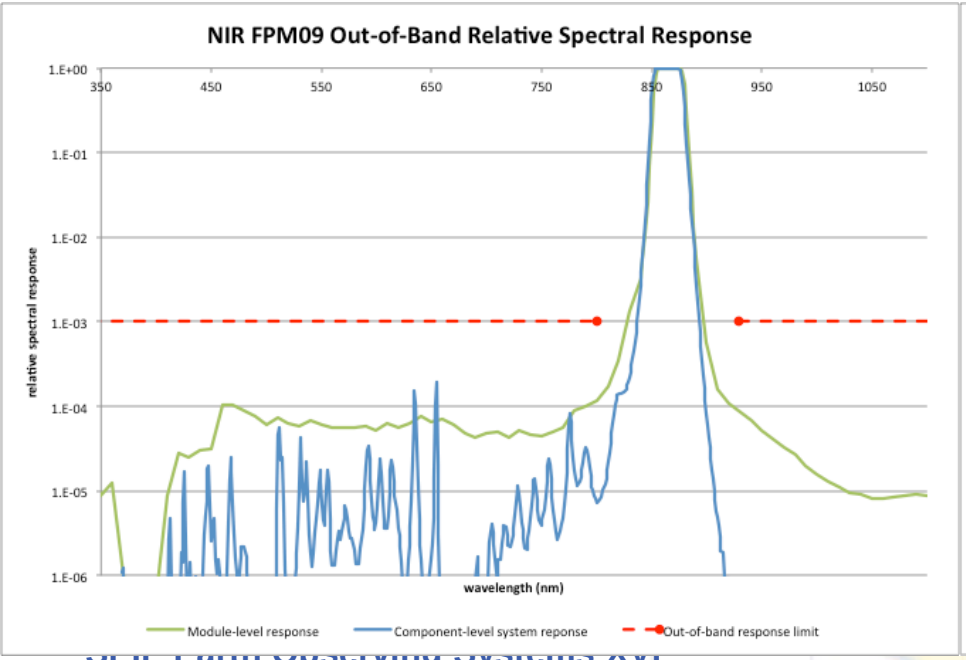
- At the module-level (assembled detector arrays and filter assemblies), tests were run on out-of-band response
  - 330-1100nm for VNIR bands
  - 800-2600nm for SWIR bands
- OLI requirement: No detector shall have a response greater than 0.001 at 50nm beyond the specified in-band wavelength (100nm for the Pan band).
  - Four detectors in the Red band did not meet this requirement.

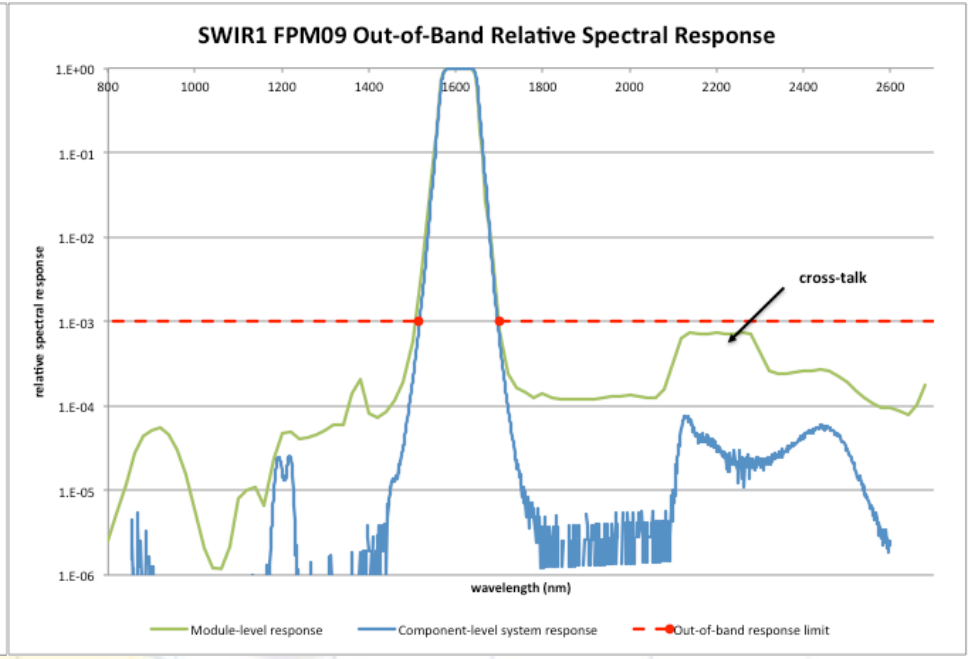




Module-level Out-of-Band measurements

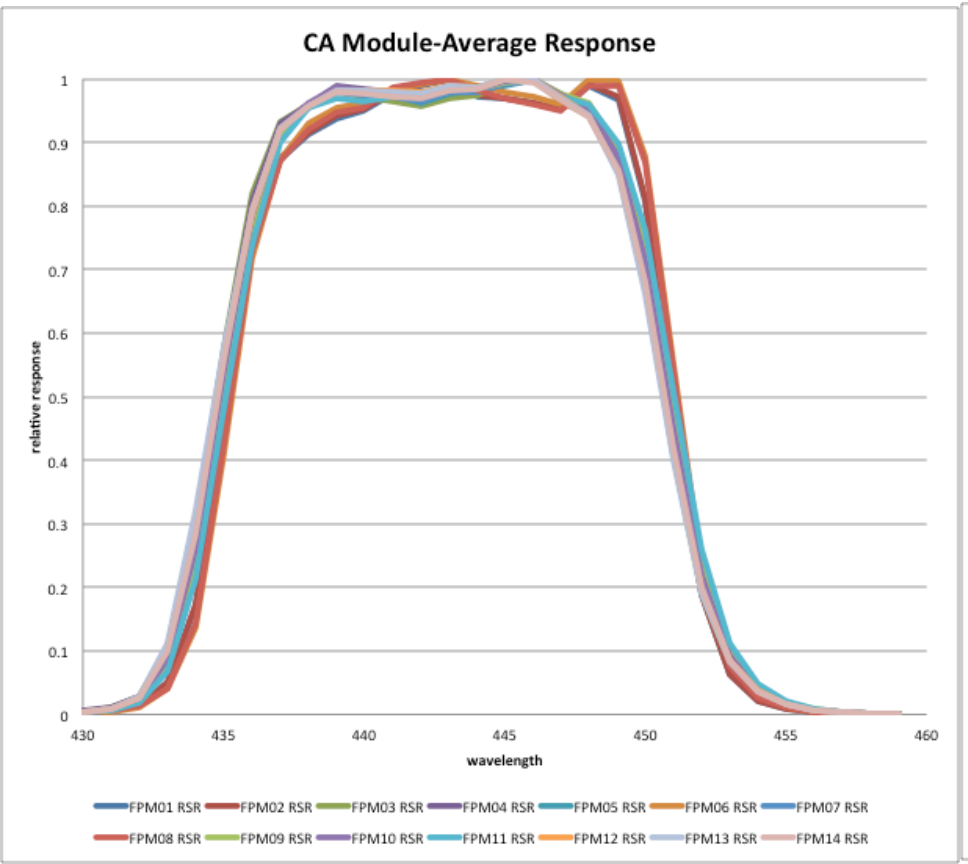
- Limited out-of-band response could be derived from the previously show component-level measurements.
- Module-level measurements revealed a spectral cross-talk feature in the SWIR bands.
  - Since the feature does not appear in the component-level measurements, the cross-talk is likely due to internal reflections in the modules.
  - Note that, thought apparent in these plots, the feature does not fail requirements.

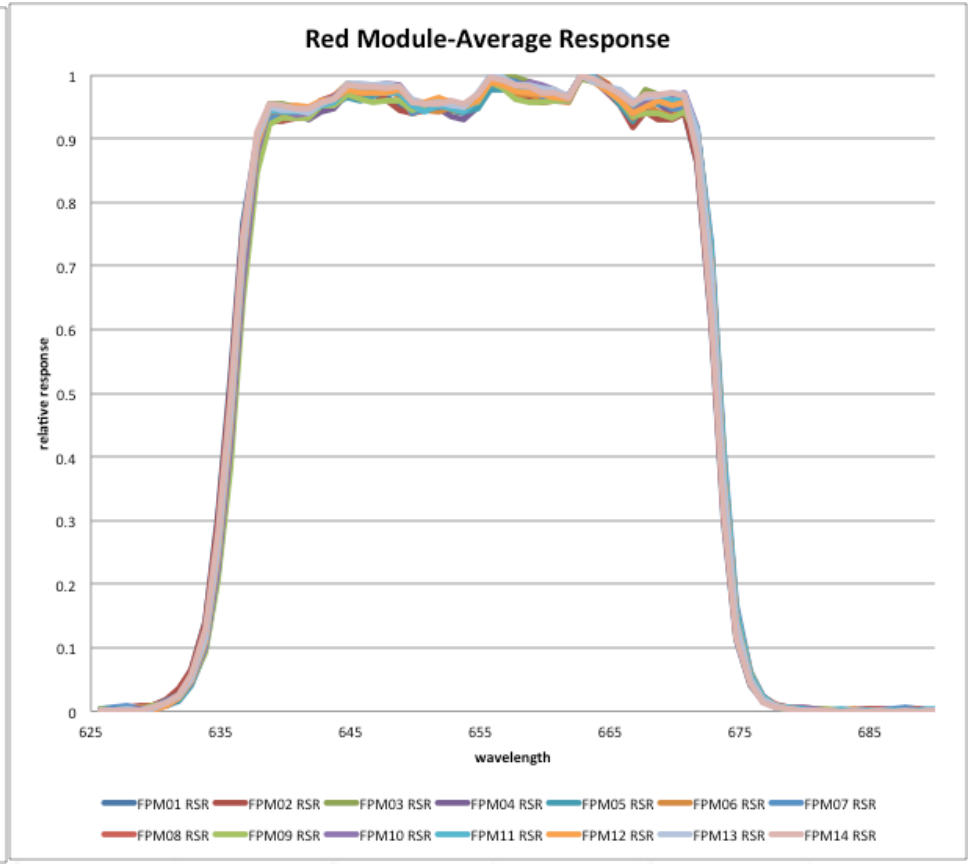




Instrument-level measurements

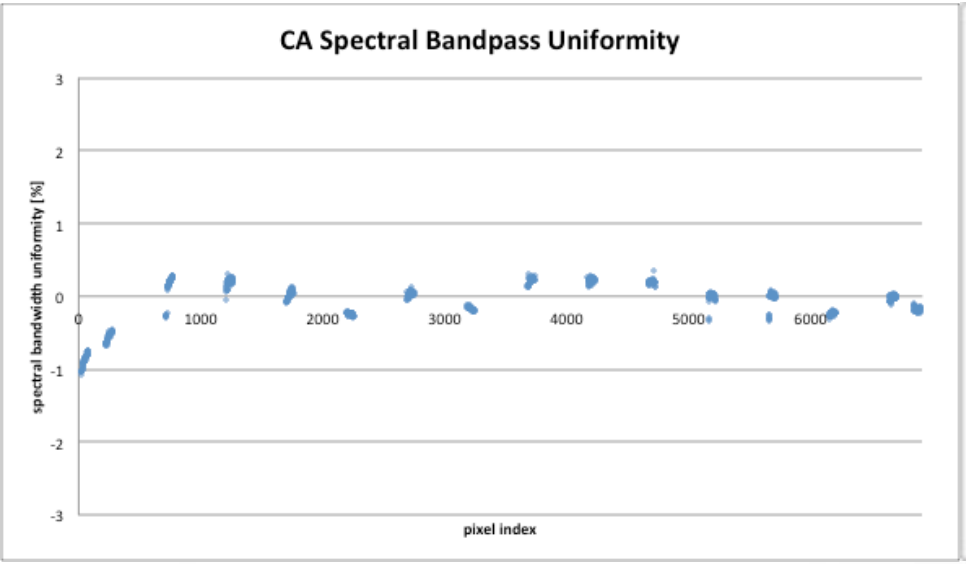
- The assembled OLI was placed in a thermal vacuum chamber for extensive characterization
- For spectral characterization, the OLI looked at a double monochromator, placed outside the chamber
- 60 detectors on each module were tested in every band

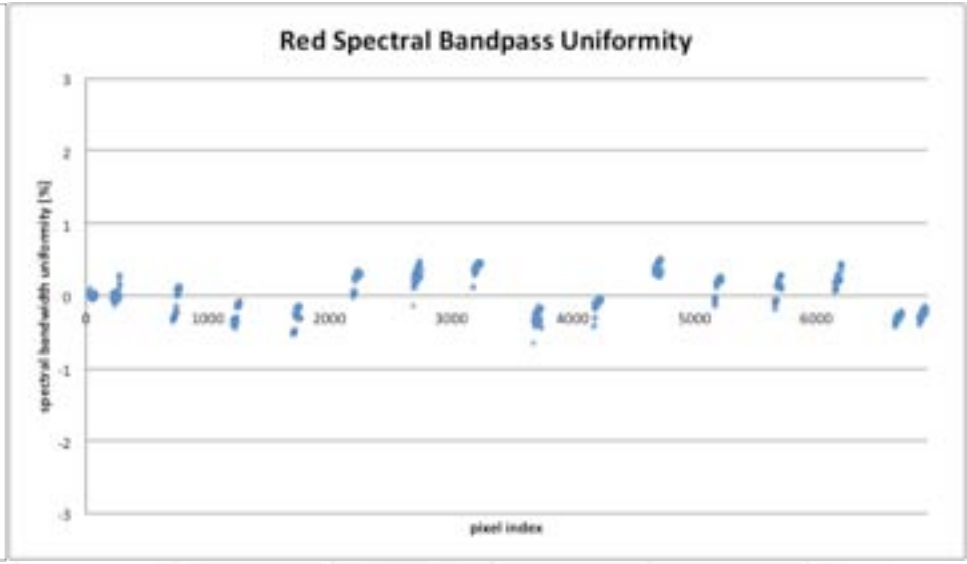




Instrument-level requirement: bandpass uniformity

- OLI Requirement on bandpass uniformity: the variation in the full-width, half maximum shall be less than +/-3% across the focal plane.





Spectral Uniformity

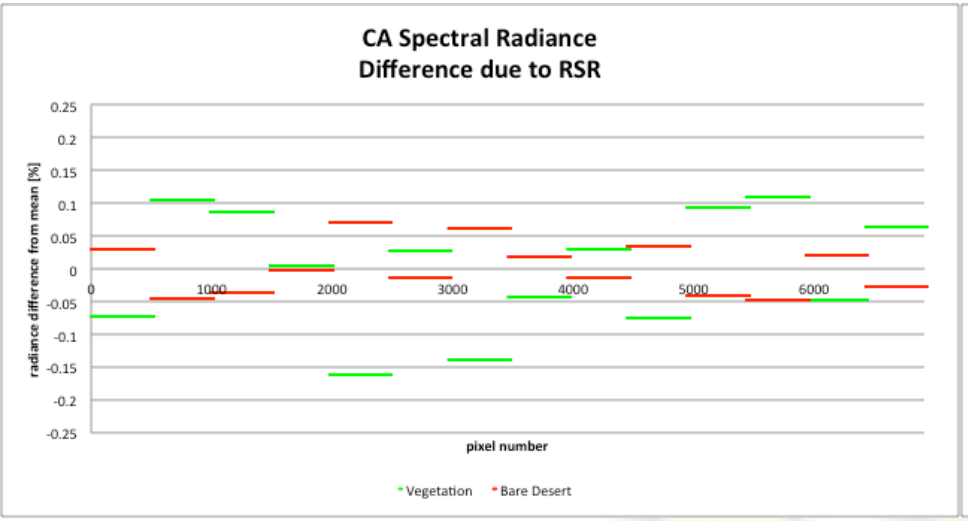
- Given the large number of detectors, variation in spectral response between pixels could result in apparent radiometric differences across the focal plane.
- Calibration process with flat-field the detectors on the solar diffuser panel
  - But spectral structure in the reflectance of actual targets will still result is spectral radiance differences
- Assess remaining spectral nonuniformity by quantifying spectral radiance differences after flat-fielding:

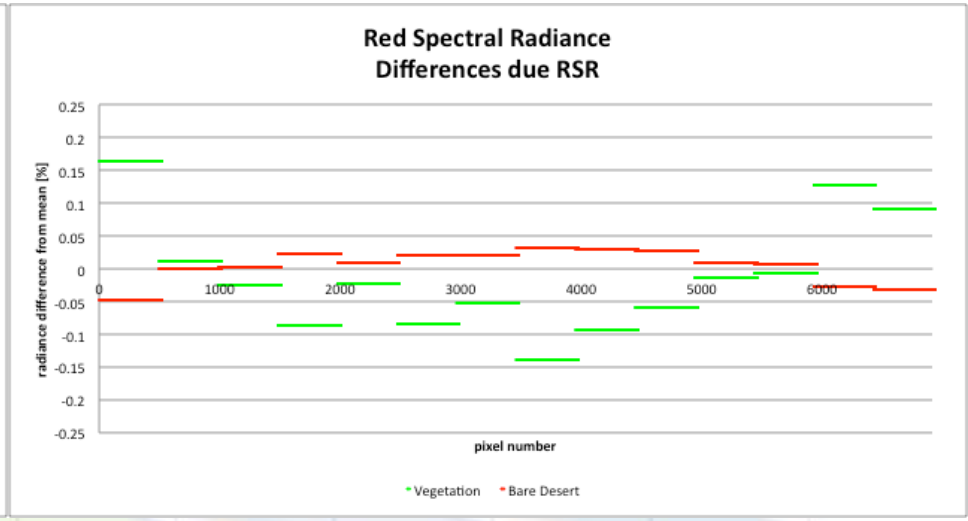
$$d = \frac{L_{\lambda,cal,ba} * L_{\lambda,target,fpm}}{L_{\lambda,target,ba} * L_{\lambda,cal,fpm}} - 1$$

- Where: the targets are vegetation and bare desert and the calibration is based on the solar radiance

Spectral Uniformity

- OLI requirement: The variation across 100 contiguous pixels cannot be greater that 0.25%
- In most bands, the maximum difference in spectral radiance across module boundaries is 0.2%
  - The Cirrus band does not meet this requirement, but the Cirrus band will not be used to differentiate surface types.



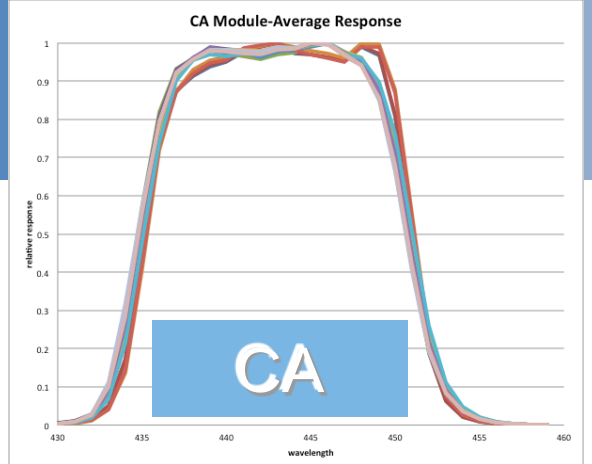


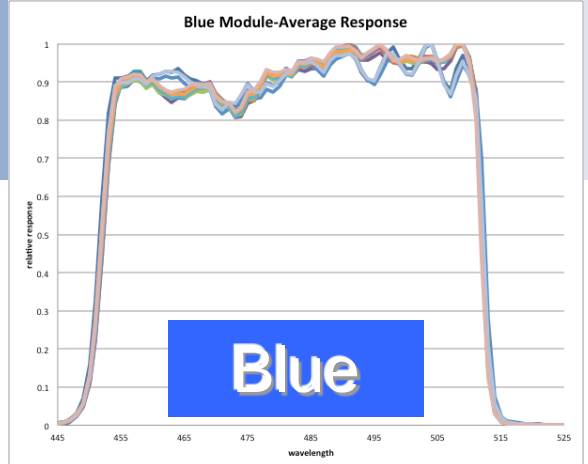
Conclusions

- Spectral Response Function has been characterized at three different levels during instrument development
- Component-level characterization: Did not reveal any issues meeting spectral requirements
- Out-of-band characterization: Four detectors out of ~70000 did not meet the out-of-band requirement
- Instrument-level characterization: All bands pass the bandpass uniformity requirement and all earth-viewing bands pass the spectral uniformity (banding) requirement.

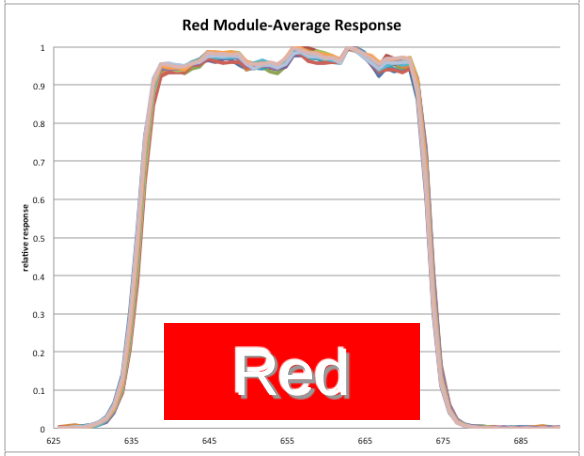
- Spectral response curves will soon be published to http://ldcm.gsfc.nasa.gov/

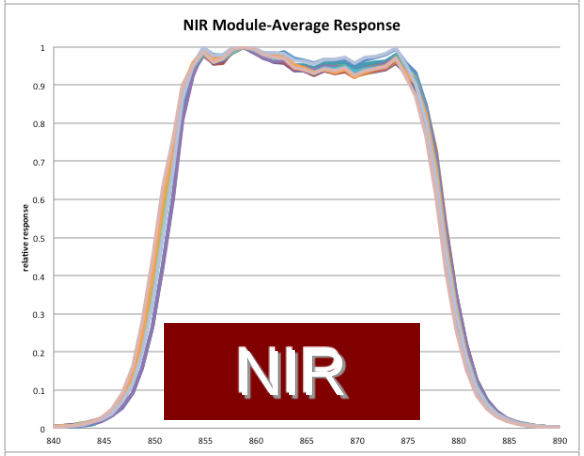
- Thanks to the team at Ball Aerospace that ran all tests and was the first to assess the characterization data.

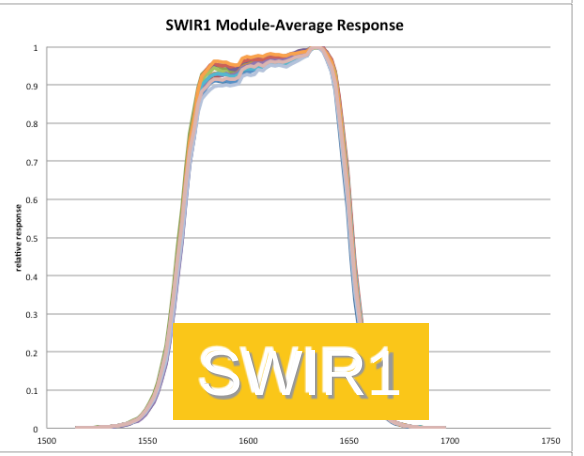

CA Module-Average Response
relative response
wavelength
CA

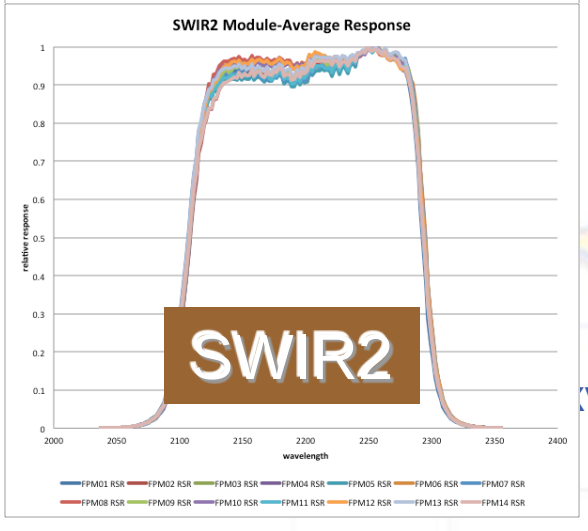

Blue Module-Average Response
relative response
wavelength
Blue

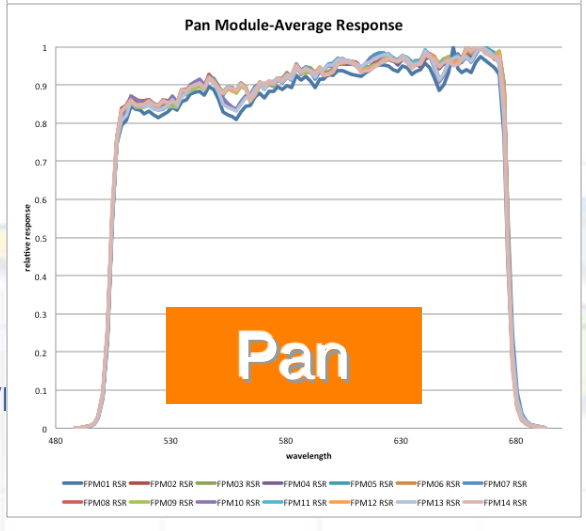
Green Module-Average Response
relative response
wavelength
Green

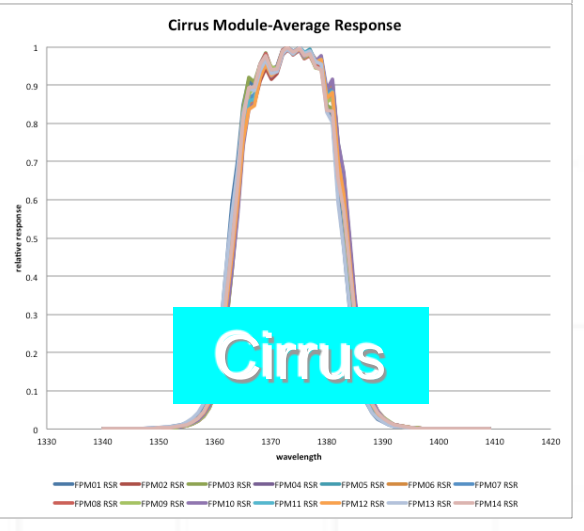

Red Module-Average Response
relative response
Red


NIR Module-Average Response
relative response
NIR


SWIR1 Module-Average Response
relative response
SWIR1

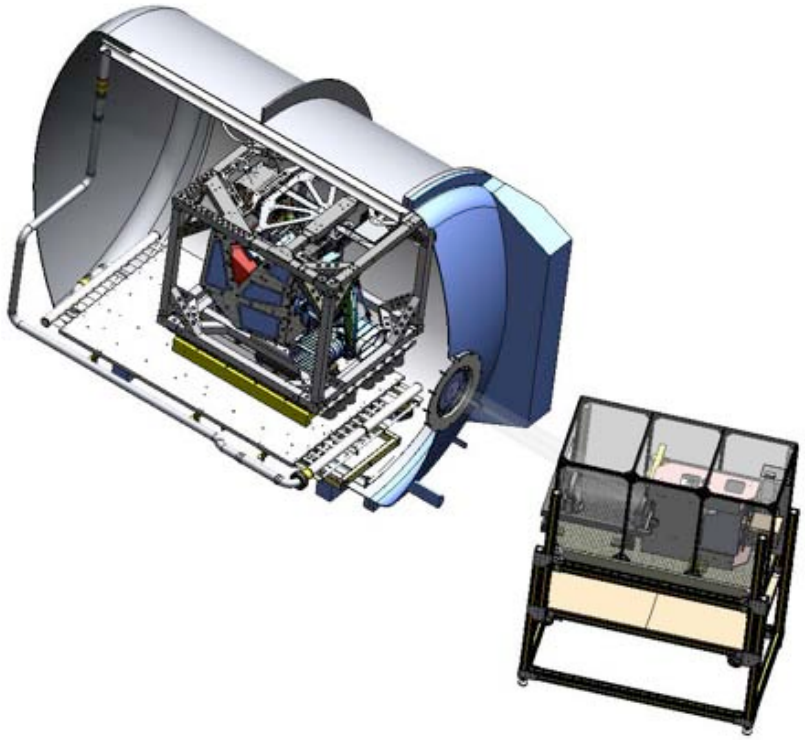

SWIR2 Module-Average Response
relative response
wavelength
SWIR2
FPM01 RSR FPM02 RSR FPM03 RSR FPM04 RSR FPM05 RSR FPM06 RSR FPM07 RSR
FPM08 RSR FPM09 RSR FPM10 RSR FPM11 RSR FPM12 RSR FPM13 RSR FPM14 RSR


Pan Module-Average Response
relative response
wavelength
Pan
FPM01 RSR FPM02 RSR FPM03 RSR FPM04 RSR FPM05 RSR FPM06 RSR FPM07 RSR
FPM08 RSR FPM09 RSR FPM10 RSR FPM11 RSR FPM12 RSR FPM13 RSR FPM14 RSR


Cirrus Module-Average Response
relative response
wavelength
Cirrus
FPM01 RSR FPM02 RSR FPM03 RSR FPM04 RSR FPM05 RSR FPM06 RSR FPM07 RSR
FPM08 RSR FPM09 RSR FPM10 RSR FPM11 RSR FPM12 RSR FPM13 RSR FPM14 RSR

Instrument-level measurements

- An assembled OLI was placed in a thermal vacuum chamber for extensive characterization
- For spectral characterization, the OLI looked at a double monochromator, placed outside the chamber
- 60 detectors on each module were tested in every band



Comparison: Instrument-level RSR vs. Component-level RSR

- For two specified targets, the integrated spectral radiance was calculated for each FPM to assess the difference between the two RSRs.
- Spectral radiance differences are generally less than 0.5%
- Final published RSRs will likely come from the instrument-level measurements
  - Following uniformity analysis is from instrument-level results

	Spectral Radiance Difference	
Band	Vegetation [%]	Bare Desert [%]
Coastal/Aerosol (CA)	-0.33	-0.66
Blue	-0.08	-0.03
Green	-0.26	0.05
Red	0.71	0.08
NIR	-0.01	0.09
SWIR 1	-0.24	0.44
SWIR 2	0.07	0.30